

Irregularities and depletion of surface water hydrology in Guinea Savannah River catchment

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ABSTRACT

The use of trend and depletion as an alternative in detecting the presence of defects in climatic variables such as rainfall and hydrological data are becoming popular. The primary goal of this study is to detect runoff anomalies, recent patterns in historical river discharge data and LULC adjustments for proper basin water supply preparation and control. Monthly rainfall and river discharge data for 31 years (1988-2018) were used for trend detection analysis. Landsat TM satellite imagery acquired in 2004, 2011, and 2018 with spatial resolutions of 30m obtained from Abuja Geographic Information Systems (AGIS) via satellite protocol was used for land use/land cover (LULC) analysis. Mann-Kendall test applied to trend analysis reveals that the rainfall data series display a growing trend. On the other hand, river discharge shows a more declining pattern than a growing trend in the discharge sequence. However, statistical significance is shown in both rainfall and river discharge data set with a p-value less than 0.05. Correspondingly, the LULC result reveals that in 14 years (2004 and 2018), the river depleted from 6.08 Km² to 4.63 km² at a rate of 0.104km² per annum. Findings indicate that the rainfall pattern and river discharge within the river watershed varied over time, as agricultural activities and other anthropogenic factors play a role other than rainfall alone. Considering the LULC result, more areas of the river are fast becoming farmlands; necessitating the need for urgent attention to safeguard the river ecosystem.

Keywords: River discharge, Mann-Kendall trend, Land Use Land Cover (LULC), Guinea Savannah.

1. INTRODUCTION

Water is an abundant chemical substance composed of hydrogen and oxygen, essential for the survival of all known life forms. Domestically, water is used for drinking, cooking, bathing, and cleaning (Yusuf *et al.* 2012). Uneven rough weather patterns determine rainfall and as a result, some areas of the world get more rainfall than others. As a result of extreme fluctuations in river discharges in some

climatic regions, dams are constructed across rivers to create water reservoirs for power generation, irrigation, flood control, recreation, and domestic water supply (Animesh and Saxena, 2011). Rivers are considered significant for domestic, industrial, and agricultural purposes (Marimuthu and Rajendran, 2017). However, Dettinger *et al.*, (2004) reported that most rivers and their water resources gradually shrink due to climate changes and anthropogenic activities. As

such, fluctuations detection and land use/land cover change are appropriate for understanding changes in river discharge trends and river watershed (Afzal *et al.*, 2011). Trend detection is a fascinating field in hydro-climatological studies that provide valuable facts that help appreciate the behaviour of river flow to assess, plan and manage the water resource (Manikannan *et al.*, 2011). The most crucial information in the basin's water resources assessment constitutes the discharged data series. Even though various trend detection techniques exist (Gray, 2007), the most commonly used are the Mann-Kendall and Sen's Slope Estimates (Walker, 1991). They are accepted on the potential to support a null hypothesis where there is no tendency and denial where bias occurs in the data collection (Daniel *et al.*, 2011). Temporal trend detection is the most crucial objective in environmental planning and management studies. As a result, changes in time-series data for rainfall, river drainage, aid preparation, construction and execution of water supply projects have been identified.

In Nigeria, River Galma is one of the largest drainage channels in Zaria in Nigeria's Savanna region as other rivers and streams discharge and empty into it. Since the establishment of the Zaria dam in 1975, it has served as a source of domestic

water to the Zaria community, irrigation, fishing and other activities related to agriculture. The primary land use in the catchment areas includes farming activities on both sides of the riverbank throughout the year and animal rearing (Aliyu *et al.*, 2019).

Adzandeh *et al.*, (2014) reported reduction and depletion of discharge in River Galma dating back to early eighties. Similarly, due to population development, the lack of water supply in the area has increased (Umar and Ankidawa, 2016). Due to booming agricultural activities and rapid urban growth, land use in the catchment is increasingly changing and significantly threatens the river's performance. The future challenges of water supplies posed by climate and anthropogenic influences are troubling; not less than 6 million people depend on this basin for livelihood. This analysis's key purpose is to determine the runoff anomalies, the latest patterns in historical river discharge data, and the LULC adjustment for the appropriate preparation and control of water supply in the basin.

2. MATERIALS AND METHODS

2.1. Study area

The River Galma acts as the primary irrigation canal for other tributaries southeast of Zaria., Nigeria. It is located on latitude 11° 10' N and

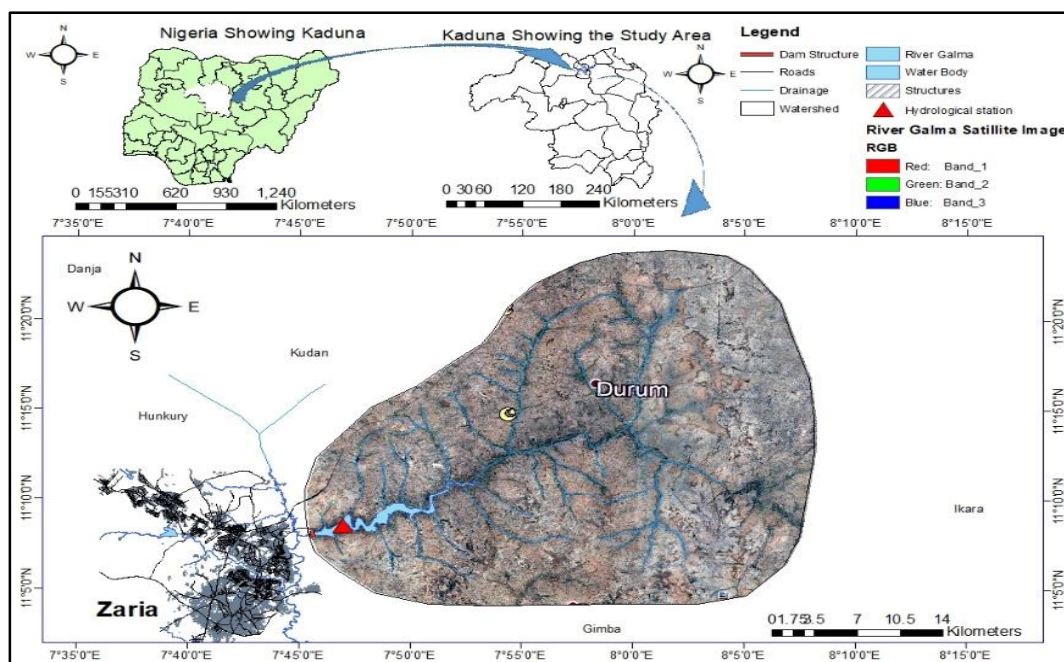


Figure 1: Watershed Satellite image of River Galma and the Hydrological Station.

longitude 7⁰.45' E (Nnaji *et al.*, 2010; Adamu *et al.*, 2020), about 128 km Southeast of Kano and 64 km to Kaduna. Zaria dam, constructed in 1975, is on this river and has a depth range from 10 meters deep, occasionally extending to about 60 meters. The dam also has a capacity of 872 million litres to supply water. The Zaria dam is a thriving agricultural region, also called the Galma dam. The area lies in the Guinea Savanna climate with alternating wet and dry seasons having farming and animal rearing as the main activities happening throughout the year on both sides of the riverbank (Figure 1).

2.2. Data collection

Monthly rainfall data of Zaria for the period of 31 years (1988 to 2018) was sourced from the meteorological agency (NIMET) station at the Nigerian College of Aviation Technology (NCAT) Zaria. Similarly, monthly river discharge data obtained over the same period from river Galma hydrological stations at River Galma Basin Development Authority (RGBDA) was used for the trend detection analysis. Other data used in this study were Landsat TM satellite imagery acquired in 2004, 2011, and 2018, all with 30m spatial resolutions, obtained from Abuja Geographic Information Systems (AGIS).

2.2.1. Data analysis

Before using suitable statistical methods, the river discharge data were subjected to Quality Assurance vs. Quality Control (QA / QC) analysis (Duhan and Pandey (2013) to check for irregularities such as incomplete details and outliers. The data was statistically cleaned after QA / QC scrutiny, with anomalies of less than 10% of the whole dataset (Brockwell and Davis, 2002). After that, the Mann-Kendall trend test and Sen's slope estimator were used for trend analysis and detection of the rate of change.

Again, a subset covering the river Galma watershed was extracted from the satellite imagery's full scene using Erdas Imagine 9.2 software. The image bands were layer stacked to produce a colour composite. Since the datasets were ortho-rectified, there was no need for Geometric correction and radiometric rectification. The satellite imageries were projected to Universal Transverse Mercator (UTM) zone 32. Geo-referencing was done to

bring all the satellite images to the same coordinate referencing system to allow overlay analysis. Supervised classification was adopted to classify the images into land use/land cover classes because of its high accuracy in mapping classes (Short, 2013). Training samples were identified and delineated on the digital image of 2004, 2011, and 2018. The objective was to determine the defined set of pixels that accurately represent spectral variation present within each information region. The data sets are classified into the following classes: bare land, water body, built-up land, farmland and vegetation using a maximum likelihood algorithm. Ground truthing helped to verify the accuracy of the image classification.

2.2.2. Trend analysis

Mann-Kendall and Sen's slope estimator statistical assessments are generally used in trend analysis and rate of change detection. Hamed and Rao (1998) reported that negative or positive autocorrelations affect time series data in this kind of analysis. However, Mann-Kendall (MK) trend test is the most used trend test tool (Yürekli 2015) to adapt missing values, outliers and data having skewed distributions (AbRazak *et al.*, 2016). As an advantage in this test, the data need not follow the normality distribution requirement. Another advantage is the low sensitivity of the test to discontinuities due to the different time series (Drápela and Drápelová, 2011). The null hypothesis (H_0) of the test is that there is no trend in the time series' values, while the alternative hypothesis (H_1) indicates a trend in the dataset. Where a 95% confidence level is used, which is at a p value less than 0.05, the test shows a significant trend (Umar *et al.*, 2019). The test is established on the statistic that;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad (1)$$

Where:

S is Man-Kendall test values,

x_j and x_k are the sequential data values,

j , k and n are the data's lengths. Sign ($x_j - x_k$) is a pointer function that assumes any of the values 1, 0, and -1, subject to the sign of ($x_j - x_k$); i.e.

$$\text{sgn}(x_j - x_k) = 1 \text{ if } x_j - x_k > 0 \quad (2)$$

$$= 0 \text{ if } x_j - x_k = 0 \quad (3)$$

$$= -1 \text{ if } x_j - x_k < 0 \quad (4)$$

Sen. (Sen, 1968) established the "Sen Slope Estimator" as a basic non-parametric test to approximate the true slope in Man-Kendall's trend study, which was later introduced by Gilbert (Duhan and Pandey, 2013). The test calculates the extent and significance of any trend detected in the Mann-Kendall test (Karpouzou *et al.*, 2010; Gocic and Trajkovic, 2013). The equation presented below is used in calculating the Sen Slope estimator.

$$Q = \frac{x_j}{j} - \frac{x_k}{k} \quad (5)$$

Q is the Sen Slope estimator value, whereas x_j and x_k are data values at times j and k .

3. RESULTS AND DISCUSSION

3.1. Descriptive statistics

Table 1 shows the results of descriptive analysis for 31 years of monthly rainfall and river discharge at River Galma with the minimum, maximum, tested means and standard deviation.

shows that it is normally distributed (Fig. 2a and b).

3.2. Hydrological trend and land use

River discharge prediction, regular proper planning and management of surface water resources require the use of previous river discharge data to be able to detect runoff irregularities and variations, thus making historical data management a crucial task. The Mann-Kendall trend test and the Sen's slope estimator applied to these secondary data and results presented in Table 2. MK trend test is used to identify any significant increases (or decreases) in monthly rainfall data set over time (Table 2RF). Based on the result, month April, May, June, July, August, September, October, and Annual indicated positive trends and the trend are statistically significant with April ($p=0.020$), May ($p=0.040$), June ($p=0.001$), July ($p=0.025$), August ($p=0.011$), September ($p=0.016$), October ($p=0.030$) and Annual ($p=0.029$) respectively (Table 2RF and Fig. 3A). But January, February, March, November, and

Table 1: Showing the descriptive statistics of the monthly rainfall distribution from (1988-2018) at river Galma watershed.

Month	Years Observed	Rainfall (RF)(mm)				River Discharge (RD) (m ³ /s)			
		Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation
JANUARY	31	0.000	0.000	0.000	0.000	3.000	14.800	11.532	2.691
FEBUARY	31	0.000	0.000	0.000	0.000	5.600	12.000	9.094	2.229
MARCH	31	0.000	7.000	0.523	1.740	3.000	12.500	8.384	2.410
APRIL	31	0.000	107.300	33.761	31.075	5.000	23.000	15.313	4.778
MAY	31	7.200	323.100	117.097	66.080	10.000	32.000	23.548	5.744
JUNE	31	125.500	407.200	231.719	62.189	11.000	64.000	39.387	11.445
JULY	31	69.300	284.400	145.352	52.536	43.000	100.000	68.419	16.278
AUGUST	31	144.700	473.100	277.526	80.099	30.000	150.000	99.226	29.135
SEPTEMBER	31	23.900	356.000	157.265	79.848	50.000	180.000	115.935	37.342
OCTOBER	31	0.000	166.100	38.287	42.717	19.000	140.000	60.581	34.778
NOVEMBER	31	0.000	0.000	0.000	0.000	7.000	37.000	19.903	9.439
DECEMBER	31	0.000	0.000	0.000	0.000	6.000	12.500	13.677	4.521
ANNUAL	31	685.600	1266.300	1001.529	146.295	20.008	53.825	40.417	8.391

Besides, the normality test was found to be within the range of -1.96 to +1.96 and -2 to +2, respectively, for river discharge data via skewness and kurtosis, suggesting that the data falls within the normal distribution of the population (George and Mallery, 2003) (Fig. 2). Normality tests were administered using Shapiro-Wilk to validate the findings of the standard normality test. This is the Mean and SD (83.33 ± 2.24 , $P=0.069$) of the river discharge data as well

December have no trend due to the absence of rainfall (Table 2RF and Fig. 3A). The monthly rainfall, the trend was statistically significant and this result is in line with the work of (Suleiman and Ifabiyi 2015) on the role of rainfall variability in reservoir storage management at Shiroro Hydropower Dam, Nigeria.

From the results in Table 2RD, January, February, March, April, May, June, July, August,

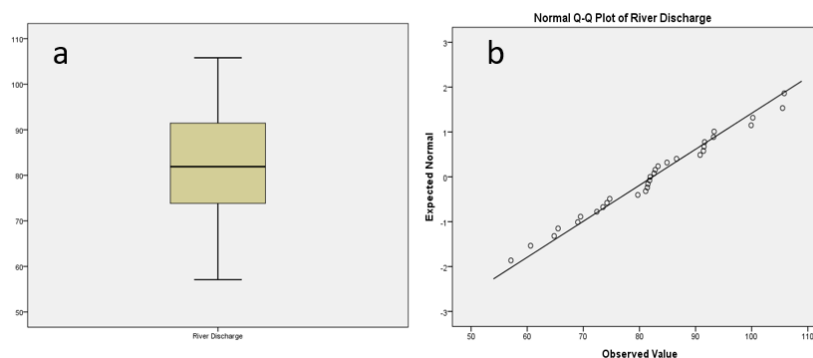


Figure 2: Box plot (a) and normal Q–Q (b) of river discharge series.

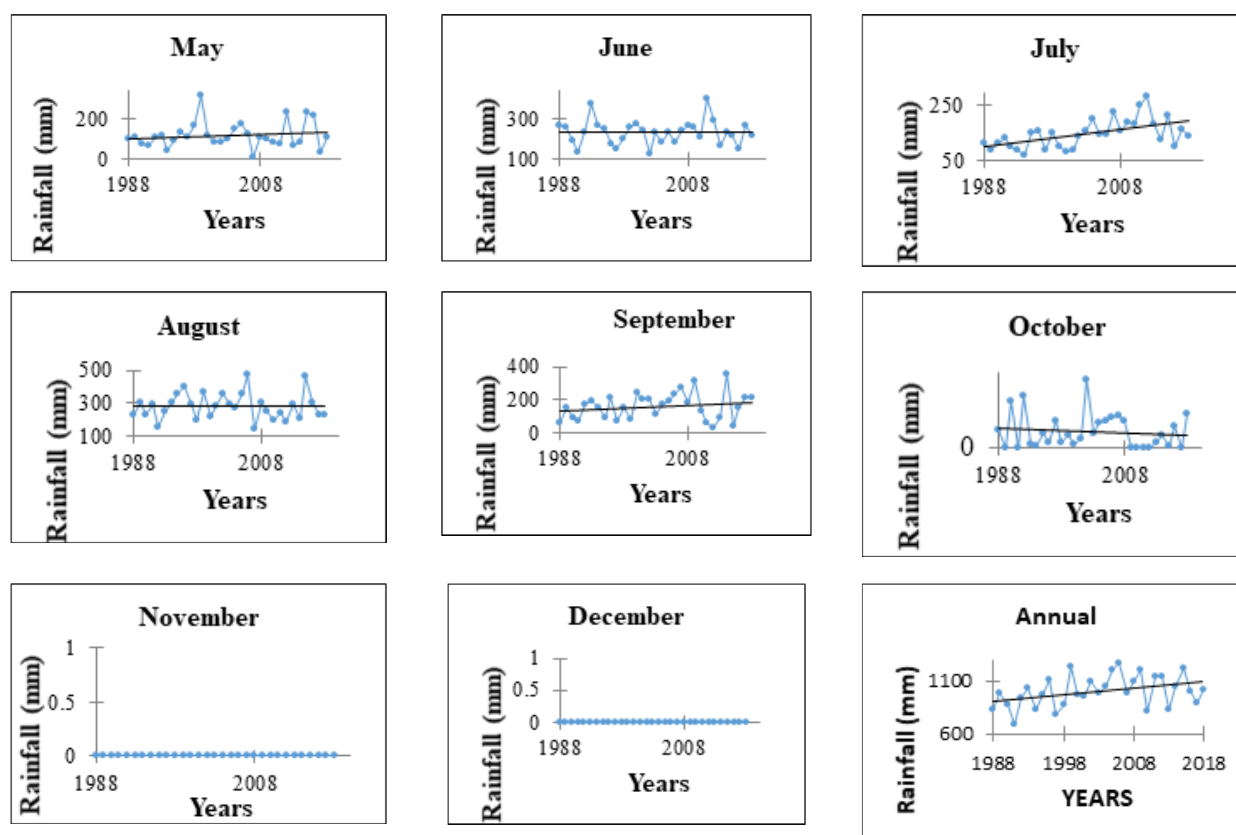


Figure 3A: Monthly Rainfall Trend from (1988-2018) in the Study Area.

September, October, November, December and the Annual values show a negative trend. This indicates that the river discharge is decreasing over the years, while the trend indicates statistical significance with p -values lower than 0.05 ($p < 0.05$) (Table 2RD and Fig. 3B). Except for January, February, November and December, which show no significance at $p=0.082$, $p=0.421$,

$p=0.759$ and $p=0.621$, respectively (Table 2RD and Fig. 3B), the results in Table 2RD and Fig. 3B show a decreasing trend in the discharge series. Therefore, it is not surprising that the water quality variation with time also shows deteriorating water quality as the concentration of the pollutant will be more apparent and clear.

Table 2: Mann–Kendall test for monthly Rainfall and River Discharge from (1988-2018)

Month	Rainfall (RF) (mm)			River Discharge (RD) (m ³ /s)		
	Mann-Kendall (MK)	p-value (P)	Slope	Mann-Kendall (MK)	p-value (P)	Slope
JANUARY	0.004	1.000	0	-0.225	0.082	-0.091
FEBUARY	0.006	1.000	0	-0.107	0.421	-0.025
MARCH	0.015	0.934	0	-0.306	0.019	-0.115
APRIL	0.078	0.020	0.316	-0.496	0.000	-0.296
MAY	0.028	0.040	0.2	-0.234	0.043	-0.208
JUNE	0.402	0.001	-0.173	-0.011	0.046	0.000
JULY	-0.026	0.025	3.150	-0.037	0.050	-0.063
AUGUST	-0.049	0.011	-0.471	-0.248	0.044	-1.250
SEPTEMBER	0.174	0.016	2.327	-0.114	0.035	-0.833
OCTOBER	-0.042	0.030	-0.019	-0.090	0.046	-0.500
NOVEMBER	0.005	1.000	0	-0.042	0.759	-0.045
DECEMBER	0.008	1.000	0	-0.066	0.621	-0.059
ANNUAL	0.277	0.029	6.385	-0.166	0.019	-0.289

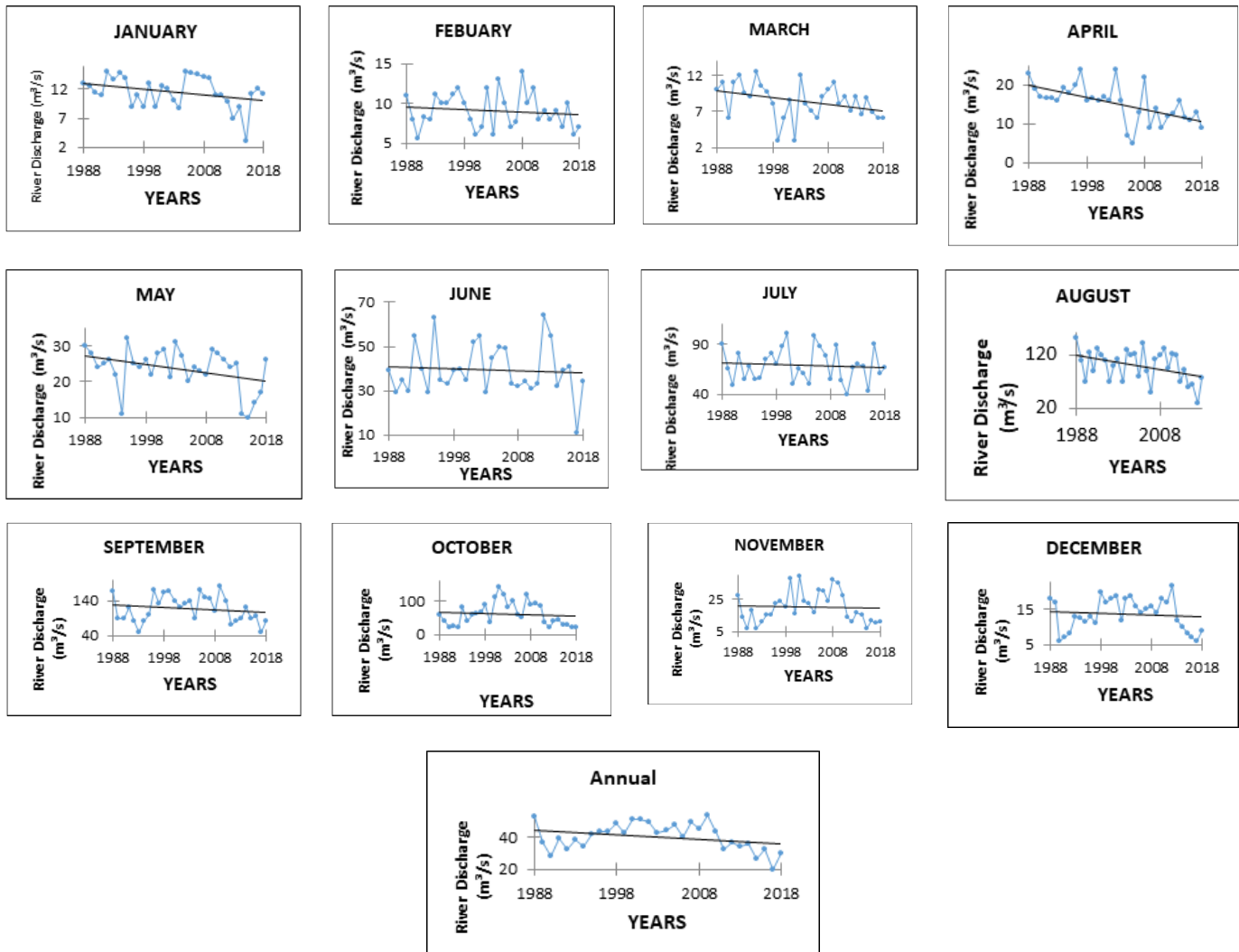


Figure 3B: Monthly River Discharge Trend from (1988-2018) in the Study Area.

3.2.1 Relationship between rainfall and river discharge at River Galma.

The pattern and relationship between rainfall as the main recharge and river discharge are reflected in the trend results. From the analysis of the correlation matrix in Table 4, the association between the environmental variables can be verified to obtain an overview of the data set, thus, identifying the variable that has a strong relationship with each at 5% significance level. Out of the two hydrological data between the data set, only variables with correlations equal to or higher than $r = 0.50$ are significant (Triola, 1999). Table 3 shows the descriptive statistic of rainfall and river discharge variables in the Galma River with the tested means and standard deviation.

Results from Table 4 shows positive association between rainfall and river discharge ($p=0.001$). Given the monthly linear association between August peak rainfall and September peak discharge, there appears to be a difference

between them (Fig. 4a). Although interaction occurs with high rainfall and river discharge in some years such as 1995, 1996, 1998, 2005, and 2009 (Fig. 4b), the average pattern varies between the rainfall and the river discharge sequence. The fact is that as the pattern of rainfall demonstrates a growing increase, the flow of the river has a reducing trend (Fig. 4b). This may be due to the fact that the hydrology of the basin is influenced by factors such as landforms, soil, vegetation, river basin scale, farming activities and other anthropogenic factors such as water extractions and seasonal variations. The findings correlate with the result of land use assessment which indicates that the river is depleted. The above agrees with (Mar and Ankidawa, 2016; Umar *et al.*, 2019) findings on climate variability and basin management. The results are also similar to the studies on rainfall irregularities, trends and variations in tropical semi-arid river catchments by Umar *et al.*, 2018.

Table 3: Descriptive statistic of rainfall and river discharge

	Mean	Std. Deviation
RF	83.0808	97.21235
RD	40.4167	37.23066

Table 4: Correlations between RF and RD

		Correlations	
		RF	RD
RF	Pearson Correlation	1	0.801**
	Sig. (1-tailed)		0.001

** . Correlation is significant at 0.01 level (1-tailed).

* Correlation significant at 0.05 level (2-tailed).

Note: RD = RF = rainfall, River discharge.

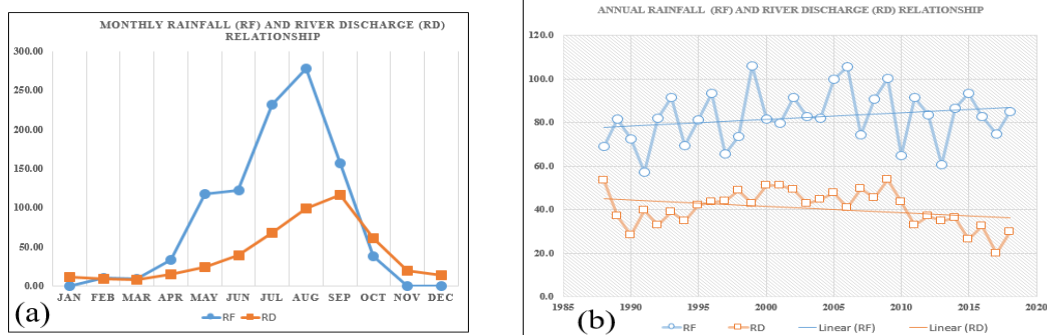


Figure 4: Relationship between rainfall and river discharge at River Galma.

3.3. Land use/land cover distribution of River Galma watershed

The results of land use/land cover assessments are presented in Table 5. Fig 5a, b, c are classified LULC images of Galma river watershed indicating the dominant land use classes in the period under study. The coverage is for almost all parts of the study area. The results show that in 2004, farmland had the most significant area coverage of 895.21 km² (76.95%), vegetation is second with 240.98 km² (20.71%), followed by built-up land (20.68 km² at 1.78%). The water Body covered 6.08 km² (0.52%), while the least coverage was bare land with 0.41 km² (0.04%)

occupation of the surrounding community is agricultural activities which lead to an increase in settlements (Muhammad *et al.*, 2014). Bare land also increases to 3.4km², gaining 2.99 km² and may be attributed to cutting down vegetation for fuel wood. Vegetation decreases to 136.05 km², losing 104.93 km² due to fuel wood harvesting and agricultural practices within the study area (Udiba *et al.*, 2014). Also, water body decreased to 4.71km², losing 1.37 km² in seven (7) years. This may be attributed to cattle rearing; sand quarrying and uncontrolled agricultural practices around the bank of the river (Yusuf *et al.*, 2012). In 2018 built-up land increased to 38.32km² with

Table 5: Land use/land cover distribution of River Galma Watershed

Land use/land cover (LULC)	2004 (km ²)	%	2011 (km ²)	%	2018 (km ²)	%
Bare Land	0.41	0.04	3.4	0.29	24.12	2.07
Water Body	6.08	0.52	4.71	0.41	4.63	0.40
Built-up Land	20.68	1.78	36.5	3.14	38.32	3.29
Farmland	895.21	76.95	982.7	84.47	956	82.18
Vegetation	240.98	20.71	136.05	11.69	140.29	12.06
Total	1163.36	100	1163.36	100	1163.36	100

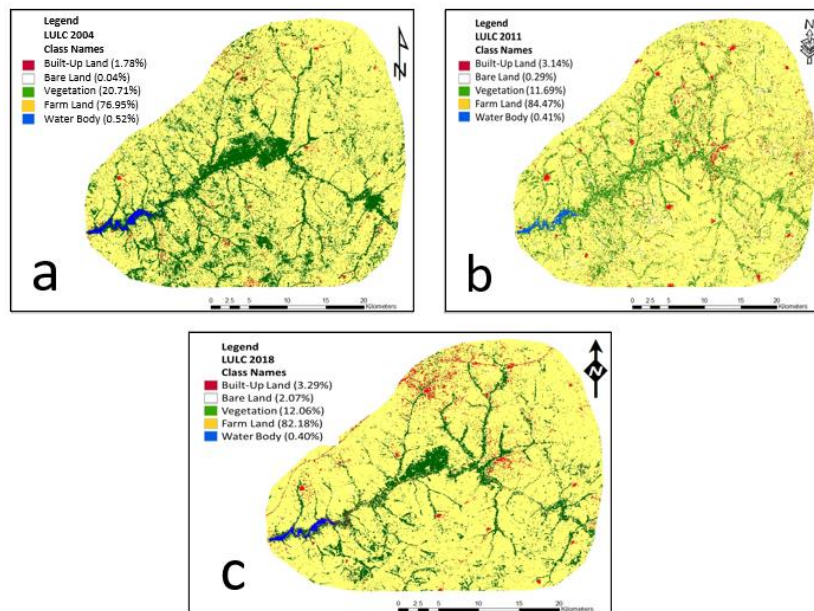


Figure 5: Land Use/Land cover change maps of River Galma.

In 2011, farmland covered an area of 982.7 km², gaining 87.49 km² in seven (7) years. Similarly, built-up land use increased from 20.68 km² to 36.5 km². This may be due to increased population around the river since the primary

a gain of 1.82km². Also, bareland increased to 24.12km², gaining 20.72km². Vegetation increased to 140.29km² (gaining 3.79km²). However, farmland decreased to 956km², losing 26.7km² while water bodies shrank to 4.63km²

losing 0.08 km². Sediment discharge attributable to sand mining at irregular distances, cultivation practices and animal grazing, cause river bank collapse and siltation of the Galma River. This agrees with Yusuf *et al.*, (2012), who recommended that cultivation and grazing near the riverbank should be discouraged to reduce the amount of sediments discharged into the river.

3.3.1 Rate of change in LULC (2004- 2018).

The rate of change in LULC in the watershed from 2004 – 2018 is presented in Table 6. The results indicate that between 2004 and 2011, the river declined at the Rate of 0.196km² per annum. Similarly, the River Galma decreased at the Rate of 0.011km² per annum, which led to the reduction of the river size to 4.63km² in 2018.

In general, between 2004 and 2018, the river reduced from 6.08 km² to 4.63 km² and declined at a rate of 0.104 km² per annum. This implies that more of the river was taken up and used for farming. This is similar to findings by Yusuf *et al.*, (2012) and Patrick *et al.*, (2015).

Generally, the behaviour and pattern of rainfall and river discharge within the river watershed varied over time. However, river basin hydrology is not affected only by rainfall but also by other variables such as soil type, flash floods, vegetation, the river basin characteristics and changes in LULC. Other factors caused by human activity, especially direct river water extraction and seasonal fluctuations, play an important role. This was not studied but may form a basis for further studies in the study area. Based on the results obtained, Geospatial techniques should be employed in monitoring river resources because they give timely and accurate results.

The findings of this study will allow administrators to prepare and maintain water resource-related projects and activities like the supply of water and irrigation, most of which rely on the availability of surface water. This will ultimately form the basis for future water supply predictions in the basin profile. In the future, using a hydrological model, a comprehensive basin-wide analysis is required to calculate

Table 6: Rate of Change in LULC in the watershed

River Period	Year	Km ²	Rate of River Change			
			Km ²	%	Km ² /Year	%/Year
2004-2011	2004	6.08	-1.37	-22.50	-0.196	-3.22
7Years	2011	4.71				
2011-2018	2011	4.71	-0.08	-1.70	-0.011	-0.23
7Years	2018	4.63				
2004-2018	2004	6.08	-1.45	-23.85	-0.104	-1.71
14Years	2018	4.63				

4. CONCLUSION

The MK trend test analysis shows statistical significance in both rainfall data and river discharge data set. However, the rainfall analysis showed statistically mixed results of increasing trends in April, May, June, July, August, September, October, and annually from 1988 to 2018 while no trend was observed in January, February, March, November, and December respectively. In contrast, the trend in river discharge has shown a clear decreasing trend than an increasing trend throughout the discharge series. Likewise, the LULC result shows a declining rate of 0.047 per annum in the Galma watershed.

potential future river flows in the River Galma basin for the proper water resource planning and management.

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